DEPARTMENT OF TRANSPORTATION WEATHER PROGRAMS

The Federal Aviation Administration (FAA) has the responsibility to provide national and international leadership in the optimization of aviation weather systems and services. This leadership is manifested through the management of a safe and efficient National Airspace System (NAS) and the encouragement of consensus and cooperation between government agencies, private weather services, research organizations, and user groups involved in aviation weather. The Federal Highway Administration (FHWA) manages programs that provide federal financial and technical assistance to the states, promotes safe commercial motor vehicle operations, and provides access to and within national forests and parks, native American reservations, and other public lands. Safety, efficiency, and mobility in these programs requires the incorporation and use of timely weather and road condition information. The Federal Railroad Administration is promotes and regulates railroad safety. It also sponsors research to enhance railroad safety and efficiency, including support for improved collection, dissemination, and application of weather information to reduce hazards to train operations and to railroad employees. The Federal Transit Administration mission is to ensure personal mobility and America's economic and community vitality by supporting high quality public transportation through leadership, technical assistance and financial resources. The United States Coast Guard (USCG) meteorological activities include the taking, collection, and transmission of marine and coastal weather warnings and observations; deployment and maintenance of offshore environmental monitoring buoys; and the operation of long-range radionavigation networks.

FEDERAL AVIATION ADMINISTRATION

AVIATION WEATHER MANAGEMENT

The Federal Aviation Administration (FAA) has the leadership role for the national aviation weather program. As the leader, FAA must conduct continual coordination for identifying needs for aviation weather products and services among the Air Traffic Control organization, the aviation industry components and among service providers. The coordination process leads to opportunities to leverage efforts and resources to form partnerships in finding solutions in response to the needs. The *National Aviation Weather Program Strategic Plan* and the *National Aviation Weather Initiatives* are two documents that formalize the coordination and partnerships. These documents comprise the first two tiers in a four tier system where funding and development of the solution are the third and fourth tiers, respectively.

The FAA focus for Aviation Weather has been to promote safety first, then improve the National Airspace System (NAS) efficiency to promote reductions in the delays and re-routing due to weather. The Administrator has launched *The Safer Skies, A Focused Safety Agenda* which includes a government/industry Commercial Aviation Safety Team (CAST) and Joint Safety Analysis Teams (JSAT) to evaluate accident investigation reports to analyze the series of events leading to the accidents, and get a sense of what and how decisions were made in the course of the flight. Other teams, Joint Safety Implementation Teams (JSIT), using the findings of the JSAT, develop and recommend intervention actions to eliminate or reduce the causes or improve the actions in the decision making process. Training about the decision making process has been identified by these teams as part of the solution.

Aviation weather information, which is complex and highly perishable, is most useful when customers can successfully plan, act, and respond in ways that avoid accidents and delays. FAA will improve the ability of the aviation community to use weather information through a review and upgrade of airmen training and certification programs. FAA will also develop multimedia training tools to support aviation safety and training initiatives. Funding has been requested to further this effort.

Weather has been made a standard consideration in all aspects of the operation and architecture of the NAS. Aviation weather needs from the field, federal agencies, and industry are entered into the FAA Acquisition Management System (AMS) through which all new programs and changes to the NAS are processed, evaluated, validated, engineered to a requirement, and acquired. The Air Traffic System Requirements Service (ARS) has the responsibility to guide all initiatives through the AMS process and organization, including the Integrated Requirements Team, the Integrated Product Team, and the Decision Boards; to assure the development continues to meet the original need; and to guide the activity should the need be evolving. ARS has added improvements to the AMS process whereby non-system or non-hardware (e.g., service improvement or rule changes) solutions will receive the same rigorous evaluation and validation. FAA has established an Aviation Weather Technology Transfer (AWTT) Board which addresses the key issues involved in bringing new capabilities in to the operational system. At key decision points, the board evaluates the maturity of the capability, its integration into the existing system, its supportability in the field, and the training program to prepare the users.

The successful execution of a national aviation weather program is first dependent upon an explicit and mutually understood definition and acceptance of roles and responsibilities both within and outside of the FAA. The execution of these roles and responsibilities have been enhanced by the chartering and complete staffing of the ARS, clarifying FAA lines of business, and completing intra-agency and interagency plans.

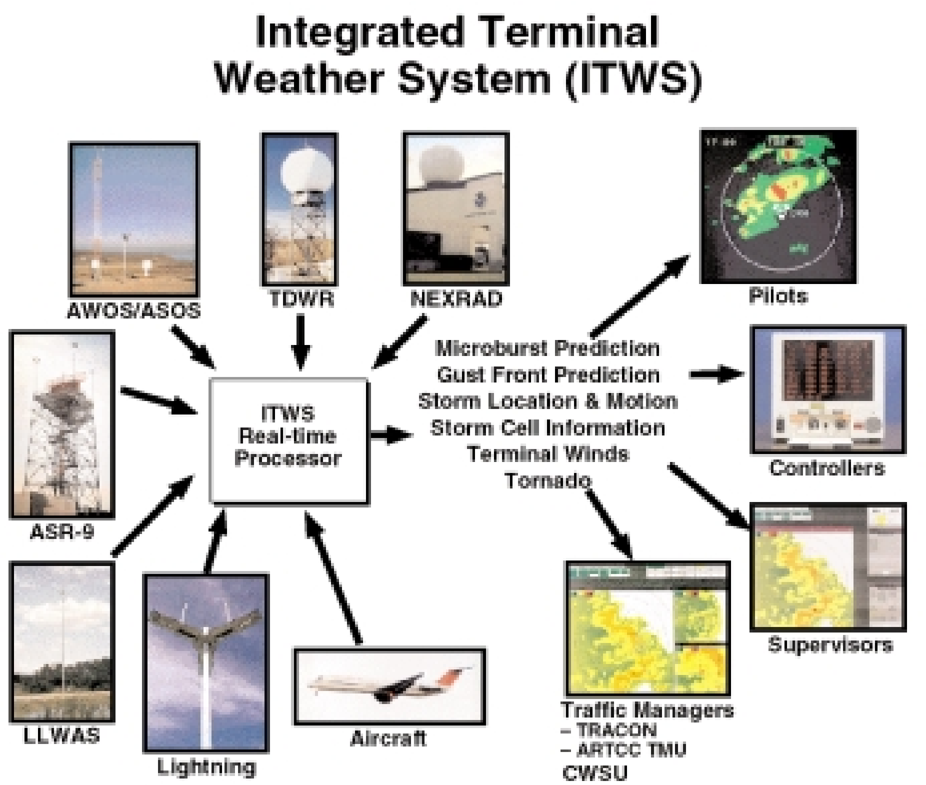

Figure 3-DOT-1. The ITWS will integrate data from FAA and NWS sensors and systems to provide a suite of weather informational products.

FAA relies on other federal agencies for weather services and support, especially NOAA's National Weather Service (NWS) and its Aviation Weather Center. Requirements validated by FAA for domestic and International Civil Aviation Organization (ICAO) users are coordinated annually and supported through the agencies and contractual arrangements. All agencies' efforts in the area of aviation weather services is coordinated for use by all as appropriate. Aviation weather technology includes the ways in which aviation weather information is gathered, assimilated, analyzed, forecast, disseminated, and displayed. The development of this technology also demands that consideration be given to human factors and the application of decision-making tools. FAA will support the use of technology to improve aviation weather information through integration of federal and non-federal resources. Automation, improved product and graphics generation, and dissemination to the cockpit offer early opportunities.

AVIATION WEATHER ACQUISITION AND SERVICES

One of the primary functions of the FAA ARS organization is the development and management of requirements for the FAA Capital Investment Plan. Recent projects in the AMS have focused on weather detection and display systems for pilots and air traffic controllers to ensure that aircraft avoid hazardous weather. The following paragraphs describe many of those projects.

The <u>Integrated Terminal Weather System</u> (ITWS) will integrate weather data from sensors in the terminal area to provide and display compatible, consistent, real-time products that require no additional interpretation by controllers or pilots--the primary users. ITWS will use data from automated surface observing systems, Doppler weather radars, and low-level wind-shear alert systems, together with NWS data and products, to forecast aviation impact parameters, such as convection, visibility, icing, and wind shear, including down bursts. Initial capabilities will include sensors available now through the early years of the 21st Century. The development is now in the demonstration phase at several airports in various climatic regimes. There will be 38 ITWSs which will provide displays at 47 high activity airports that are supported by terminal doppler weather radars. (Figure 3-DOT-1).

The Corridor Integrated Weather System (CIWS) is a new program which will take most of the capabilities of the integration software of the ITWS and expand it to cover larger areas beyond the terminals. 'Corridor' in the name implies the area covered will be an elongated zone which may include a number of terminal areas (e.g., the area over Cleveland and Pittsburgh connecting Chicago and New York). The CIWS is expected to integrate information from many observing sensors in the corridor to produce weather information products on current conditions affecting en route traffic in such a major corridor. Details on this program are being formulated.

The Terminal Doppler Weather Radar (TDWR) program consists of the procurement and installation of a new terminal weather radar based on Doppler techniques. TDWR units have been located to optimize the detection of microbursts and wind shear at selected high operations and weather activity airports. In addition, TDWR has the capability to identify areas of precipitation and the locations of thunderstorms (Figure 3-DOT-2).

Microbursts are weather phenomenon that consist of an intense down draft with strong surface outflows. They are particularly dangerous to aircraft that are landing or departing. TDWR scanning strategy is optimized for microburst/wind shear detection. The radars are located near the airport operating areas in a way to best scan the runways as well as the approach and departure corridors. The displays are located in the tower cab and Terminal Radar Approach Control (TRACON).

Figure 3-DOT-2. FAA Terminal Doppler Weather Radars provide supplementary wind and precipitation conditions for airport approach and departure.

FAA has 45 TDWR systems commissioned and the remaining 2 systems will be commissioned by the end of calendar year (CY) 2002. A software upgrade which integrates TDWR and low level wind shear alert system data has been integrated at 9 high traffic/high weather threat airports.

The Low Level Wind Shear Alert System (LLWAS) provides pilots with information on hazardous wind shear that create unsafe conditions for aircraft landings and departures. A total of 110 airports have LLWAS. The 101 basic systems, LLWAS-2, consists of a wind sensor located at center field and 5 to 32 sensors near the periphery of the airport (Figure 3-DOT-3). A computer processes the sensor information and displays wind shear conditions on a ribbon display to air traffic controllers for relay to pilots. The improvement phase, referred to as LLWAS-Relocation/Sustainment (LLWAS-RS), will include expanding the network of sensors, developing improved algorithms for the expanded network, and installing new information/alert displays. The new information/alert displays will enable controllers to provide pilots with head wind gain or loss estimates for specific runways. These improvements will increase the system's wind shear detection capability and reduce false alarms. Improvements are also expected to reduce maintenance costs. Currently, LLWAS–RS are being deployed and should be completed by mid fiscal year (FY) 2003.

The Weather Systems Processor (WSP) program provides an additional radar channel for processing weather returns and de-alias returns from the other weather channel in the ASR-9. The displays of convective weather, microbursts, and other wind shear events will provide information for controllers and pilots to help aircraft avoid those hazards. A prototype has been demonstrated and limited production has commenced. Full production deliveries are expected to be completed in FY 2002.

The Terminal Weather Information for Pilots (TWIP) program provides text message descriptions and character graphic depiction of potentially hazardous weather conditions in the terminal area of airports with installed TDWR systems. TWIP provides pilots with information on regions of moderate to heavy precipitation, gust fronts, and microburst conditions. The TWIP capability is incorporated in the TDWR software application. Text messages or character graphic depiction are received in the cockpit through the Aeronautical Radio Incorporated (ARINC) Communication Addressing and Reporting System (ACARS) data link system. A total of 47 TDWR systems will be deployed with 45 of those currently installed and commissioned. The TWIP capability is operational at 31 of the TDWR sites. Activation of TWIP at the remaining sites is dependent on availability of National Airspace Data Interchange Network (NADIN) II connectivity and program funding.

The Flight Information System (FIS) Policy was implemented during FY 2001, through Government-Industry Project Performance Agreements (G-IPPAs) with two industry FIS data link service providers (ARNAV Systems, Inc. and Honeywell International, Inc.). Through the government-industry agreements, the FAA provides access to four VHF channels (136.425-136.500) in the aeronautical spectrum while industry provides the ground infrastructure for data link broadcasts of text and graphic FIS products at no cost to the FAA. Under the agreements, a basic set of text products are provided at no fee to the pilot users while industry may charge subscription fees for other value-added text and graphic products.

The FAA FIS data link program will continue development of necessary standards and guidelines supporting inter-operability and operational use. In addition, the need and feasibility for establishing a national capability for collecting and distributing electronic pilot reports (E-PIREPs) from low-altitude general aviation operations is being evaluated. Also, in FY 2001 a concept analysis will be initiated to define the need for transition and evolution of FIS data link services supporting the future NAS architecture including Free Flight operations.

SURFACE WEATHER OBSERVING PROGRAM

Aviation Weather Observations. The FAA has taken responsibility for aviation weather observations at many airports across the country. To provide the appropriate observational service, FAA is using automated systems, human observers, or a mix of the two. It has been necessary to place airports into four categories according to the number of operations per year, any special designation for the airport, and the frequency at which the airport is impacted by weather.

- Level D service is provided by a stand-alone Automated Weather Observing System (AWOS) or an Automated Surface Observing System (ASOS). In the future, Level D service may be available at as many as 400 airports.

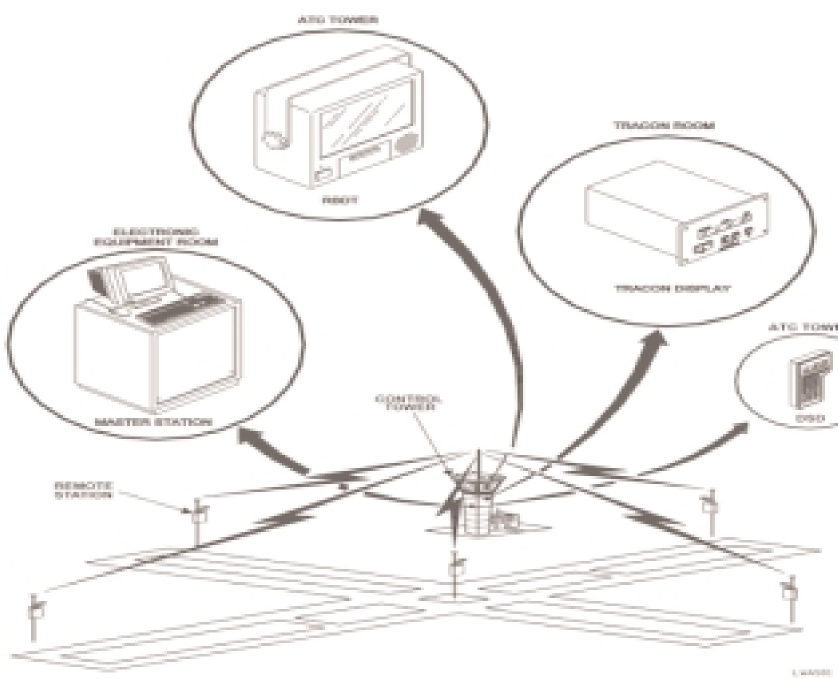

Figure 3-DOT-3. LLWAS equipment on an airfield.

- Level C service includes the ASOS/AWOS plus augmentation by tower personnel. Tower personnel will add to the report observations of thunderstorms, tornadoes, hail, tower visibility, volcanic ash, and virga when the tower is in operation. Level C service includes about 250 airports.
- Level B service includes all of the weather parameters in Level C service plus Runway Visual Range (RVR) and the following parameters when observed--freezing drizzle versus freezing rain, ice pellets, snow depth, snow increasing rapidly remarks, thunderstorm/lightning location remarks, and remarks for observed significant weather not at the station. Level B service includes about 57 airports.
- Level A service includes all of the weather parameters in Level B service plus 10-minute averaged RVR for long-line transmission or additional visibility increments of 1/8, 1/16, and 0 miles. Level A service includes about 78 airports.

Automated surface aviation weather observing systems will provide aviation-critical weather data (e.g., wind velocity, temperature, dew point, altimeter setting, cloud height, visibility, and precipitation--type, occurrence, and accumulation) through the use of automated sensors. These systems will process data and allow dissemination of output information to a variety of users, including pilots via computer-generated voice.

Automated Weather Observing Systems (AWOS) was deployed at over 200 airports to provide the basic aviation weather observation information directly to pilots approaching the airport. The majority of these systems were installed at various non-towered airports to enhance aviation safety and the efficiency of flight operations by providing real-time weather data at airports that previously did not have local weather reporting capability. These systems are built to the standards of quality necessary to ensure the safety of flight operations and are available off-the-shelf as a commercial product. There remain 198 AWOSs.

Automated Surface Observing Systems (ASOS). In a joint program with NOAA NWS, the FAA has procured, installed, and operates ASOS at the remaining airports where the FAA provides observations and at additional non-towered airports without weather reporting capabilities in accord with the levels of service listed above. Production is complete and the FAA has 569 systems installed and commissioned.

Aviation Weather Sensor Systems (AWSS), a new program, will have capability similar to ASOS. However, the AWSS is a direct acquisition of the FAA and not from the joint program. Full production may begin in FY 2002, pending funding, with commissioning completed in FY 2003.

The AWOS/ASOS Data Acquisition System (ADAS) functions primarily as a message concentrator and will collect weather messages from AWOS and ASOS equipment located at controlled and non-controlled airports within each air route traffic control center's (ARTCC) area of responsibility. ADAS will distribute minute-by-minute AWOS/ASOS data to the Weather and Radar Processor (WARP) within the air route traffic control center in which it is installed. ADAS will also distribute AWOS data to the NADIN which will in-turn forward the data to Weather Message Switching Center Replacement (WMSCR) for further distribution. Field implementation of ADAS has been completed.

The Automated Lightning Detection and Reporting System (ALDARS) is a system adjunct to the ADAS. ALDARS collects lightning stroke information from the National Lightning Detection Network (NLDN) and disseminates this data to AWOS/ASOS for the reporting of thunderstorms in METAR or SPECI observations, when appropriate. The use of ALDARS eliminates the need for manual reporting of thunderstorms and increases the number of airports where thunderstorms will be reported. ALDARS is completely operational.

Stand Alone Weather Sensors (SAWS) are planned to be back-up for some AWOS/ASOS sensors at locations where no other back-up capability is available. SAWS is in the demonstration phase with full delivery expected in CY 2002.

AWOS for Non-Federal Applications. Under the Airport Improvement Program (AIP), state and other local jurisdictions may justify to the FAA their need to enhance their airport facilities. Upon approval, these improvements may be partially funded by the FAA using resources from the Airway Trust Fund. The local airport authority becomes responsible for the remainder of the funding necessary to complete the procurement as well as the funding for the regular maintenance. The addition of an AWOS is one of the improvements that qualify for AIP funding assistance. Systems that qualify must meet certain standards which are defined in an FAA Advisory Circular on Non-Federal Automated Weather Observing Systems.

There are more than 275 non-Federal AWOS locations. Some of these are capable of reporting through a geostationary communications satellite; many more will acquire that capability during the year. These observations will be entered into the national network for use in support of the NAS and the national weather network.

The New Generation Runway Visual Range (NRVR) program provides for a new generation RVR sub-element of the NAS. The NRVR provides runway visual range information to controllers and users in support of precision landing and take-off operations. The NRVR incorporates state-of-the-art sensor technology and embedded remote maintenance monitoring. FAA plans to procure and install these NRVR systems at all new qualifying locations. FAA plans also call for the replacement of many existing RVRs in the NAS inventory.

The NRVR provides for near real-time measurement of visibility conditions along a runway (up to three points along the runway can be measured-- touchdown, midpoint, and roll-out) and reports these visibility conditions to air traffic controllers and other users. The system automatically collects and formats data from three sensors: a visibility sensor--forward scatter meters will replace the transmissometers currently in use, a runway light intensity monitor for both runway edges and center-line lights, and an ambient light sensor which controls computer calculations using a day or night algorithm. The data processing unit calculates runway visibility products and distributes the products to controllers and other users.

NRVR visibility sensors will be deployed at 308 airports. Delivery of the NRVR sensors began in November 1998. To date, 208 have been delivered and 172 have been commissioned. At the current levels of annual funding, the program will have completed the deployment by the end of CY 2009.

The FAA is procuring the Operational and Supportability Implementation System (OASIS) to improve weather products, flight information, aeronautical data collection, analysis, and timeliness of dissemination and, thereby, enhance the safety and efficiency of the NAS. OASIS will replace the Model-1 Full Capacity Flight Service Automation System, which includes the Aviation Weather Processor. OASIS will also integrate the Interim Graphic Weather Display System functions and include several automated flight service data handling capabilities. This configuration will be its initial deployment capability. Operational testing began in 1999; deployment will commence in FY 2002.

Future enhancements leading to the full capability deployment will include: interactive alphanumeric and graphic weather briefings, direct user access terminal (DUAT) service functionality, automated special use airspace, and training support. OASIS will support flight planning, weather briefings, NOTAM service, search and rescue, and pilot access terminal services.

The Next Generation Weather Radar (NEXRAD), known operationally as the Weather Surveillance Radar-1988 Doppler (WSR-88D), is a multi-agency program that defined, developed, and implemented the new weather radar. Field implementation began in 1990 and was completed in 1996. There are a total of 161 WSR-88D systems deployed. The FAA sponsored 12 systems in Alaska, Hawaii, and the Caribbean. DOC and DOD WSR–88Ds provide coverage over the continental United States.

The FAA emphasized the development of WSR-88D algorithms that take advantage of the improved detection of precipitation, wind velocity, and hazardous storms. The FAA also stressed that these algorithms provide new or improved aviation-oriented products. These improvements in detection of hazardous weather will reduce flight delays and improve flight planning services through aviation weather products related to wind, wind shear, thunderstorm detection, storm movement prediction, precipitation, hail, frontal activity, and mesocyclones and tornadoes. WSR-88D data provided to ATC through the WARP will increase aviation safety and fuel efficiency.

In addition, the three funding agencies support the field sites through the WSR-88D Radar Operations Center (ROC) at Norman, Oklahoma. The ROC provides software maintenance, operational troubleshooting, configuration control, and training. Planned product improvements include a shift to an open architecture, new antenna design, dual polarization, and the development of more algorithms associated with specific weather events, such as hurricanes.

The Air Route Surveillance Radar (ARSR-4) provides the ARTCCs with accurate multiple weather levels out to 200 nautical miles. The ARSR-4 is the first en route radar with the ability to accurately report targets in weather. The ARSR-4 can provide weather information to supplement other sources. The ARSR-4 is a joint FAA/USAF funded project. Forty joint radar sites were installed during the 1992-1995 period.

The Weather and Radar Processor (WARP), Stage 0 has replaced the Meteorologists Weather Processor to provide aviation weather information to the Center Weather Service Units. Stage 1 and 2 will automatically create unique regional, WSR-88D-based, mosaic products, and send these products, along with other time-critical weather information, to controllers through the Display System Replacement and to pilots via the FIS. WARP will greatly enhance the dissemination of aviation weather information throughout the NAS. WARP is currently undergoing operational testing and evaluation and will be fielded at the ARTCCs in FY 2003.

The Direct User Access Terminal (DUAT) system has been operational since February 1990. Through DUAT, pilots are able to access weather and NOTAMs and also file their IFR and/or VFR flight plans from their home or office personal computer. This system will eventually be absorbed into OASIS.

AVIATION WEATHER COMMUNICATIONS

It should be noted that FAA communications systems are multi-purpose. Weather data, products, and information constitute a large percentage of the traffic, as do NOTAMS, flight plans, and other aeronautical data.

The National Airspace Data Interchange Network (NADIN II) packet-switched network was implemented to serve as the primary interfacility data communications resource for a large community of NAS computer subsystems. The network design incorporates packet-switching technology into a highly connected backbone network which provides extremely high data flow capacity and efficiency to the network users. NADIN II consists of operational switching nodes at two network control centers (and nodes) at the National Aviation Weather Processing Facilities at Salt Lake City, Utah, and Atlanta, Georgia. It will interface directly to Weather Message Switching Center Replacement (WMSCR), WARP, ADAS, TMS, and the Consolidated NOTAM System. NADIN II also may be used as the intra-facility communications system between these (collocated) users during transition to end state.

The Weather Message Switching Center Replacement (WMSCR) replaced the Weather Message Switching Center (WMSC) located at FAA's National Communications Center (NATCOM), Kansas City, Missouri, with state-of-the-art technology. WMSCR performs all current alphanumeric weather data handling functions of the WMSC and the storage and distribution of NOTAMs. WMSCR will rely on NADIN for a majority of its communications support. The system will accommodate graphic data and function as the primary FAA gateway to the NWS' National Centers for Environmental Prediction (NCEP)--the principal source of NWS products for the NAS.

To provide for geographic redundancy, the system has nodes in the NADIN buildings in Atlanta, Georgia, and Salt Lake City, Utah. Each node supports approximately one-half of the United States and will continuously exchange information with the other to ensure that both nodes have identical national databases. In the event of a nodal failure, the surviving one will assume responsibility for dissemination to the entire network.

Currently, specifications for an upgrade or replacement for the WMSCR are being formulated. The needs, when developed, will be entered into the AMS process for validation and acceptance into the NAS architecture.

The Flight Information Service (FIS) is a new communications systems to provide weather information to pilots in the cockpit. FIS is a partnership program among the government and private industry with the government providing the base information and the bandwidth while the private companies provide the broadcast and value-added products. New products are screened for technical suitability and value to the pilots. Two companies have demonstrated preliminary products and capability.

The Worldwide Aeronautical Forecast System (WAFS) is a three geosynchronous satellite-based system for collecting and disseminating aviation weather information and products to/from domestic or international aviation offices as well as in-flight aircraft. The information and products are prepared at designated offices in Washington, District of Columbia, and Bracknell, United Kingdom. The United States portion of WAFS is a joint project of the FAA and NWS to meet requirements of the ICAO member states. FAA funds the satellite communications link and the NWS provides the information/product stream.

Two of the three satellites are funded by the United States. The first is located over the western Atlantic with a footprint covering western Africa and Europe, the Atlantic Ocean, South America, and North America (except for the West Coast and Alaska). The second United States-funded satellite is positioned over the Pacific and covers the United States West Coast and Alaska, the Pacific Ocean, and the Pacific rim of Asia. The third satellite, operated by the United Kingdom, is stationed over the western Indian Ocean and covers the remaining areas of Europe, Asia, and Africa. The data available via WAFS include flight winds, observations, forecasts, SIGMETs, AIRMETs, and hazards to aviation including volcanic ash clouds.

AVIATION WEATHER RESEARCH PROGRAM

Working closely with the Integrated Product Team for Weather/Flight Services Systems, ARW sponsors research on specific aviation weather phenomena which are hazardous and/or limiting to aircraft operations. This research is performed through collaborative efforts with the National Science Foundation (NSF), NOAA, NASA, and the Massachusetts Institute of Technology's Lincoln Laboratory. A primary concern is the effective management of limited research, engineering, and development resources and their direct application to known deficiencies and technical enhancements.

Improved Aircraft Icing Forecasts. The purpose of this initiative is to establish a comprehensive multi-year research and development effort to improve aircraft icing forecasts as described in the FAA Aircraft Icing Plan. The objectives of this plan are to develop: (1) an icing severity index, (2) icing guidance models, and (3) a better comprehension of synoptic and mesoscale conditions leading to in-flight icing. The result of this effort will be an improved icing forecasting capability that provides pilots with more timely and accurate forecasts of actual and expected icing areas by location, altitude, duration, and potential severity.

Figure 3-DOT-4. Convective Sigmet graphics are produced by the Aviation Weather Center and accessible to pilots from their web site. (Source: AWC web site)

Convective Weather Forecasting. The purpose of this research effort is to establish more comprehensive knowledge of the conditions that trigger convection and thunderstorms and, in general, the dynamics of a thunderstorm's life cycle. The program will lead to enhanced capability to predict growth, areal extent, movement, and type of precipitation from thunderstorms. Gaining this forecast capability will allow better use of the airspace and help aircraft avoid areas with hazardous convective conditions (Figure 3-DOT-4).

Model Development and Enhancement. This research is aimed at developing or improving models to better characterize the state of the atmosphere and stratosphere in general, with specific emphasis on the flight operation environment specifically, with the aim to provide superior aviation weather products to end users.

Aviation Forecast and Quality Assurance (AF&QA). The Product Development Team for AFGS is working on the development of products for dissemination on the Aviation Digital Data System. New algorithms will be developed to present hazardous conditions in the flight operations environment. They will develop a process for automated production of the SIGMETs. There will be capability to assure quality and a real-time verification process.

Weather Support to Deicing Decision Making (WSDDM). This system develops products that provide forecasts on the intensity of snow and freezing rain, and how or when these phenomena will change in the short term. This information is needed by airport management to determine when an aircraft will require deicing before take-off. The water content of snow is believed to be an important factor. The output product is designed for non-meteorological aviation users and has been demonstrated at three different airports. Development work has been completed and FAA has made this system available to airport authorities who wish to use it as a decision aid.

Ceiling and Visibility. A development and demonstration is underway in the San Francisco Bay area. The project will have unique sensors and the data will be used in new algorithms to develop improved forecasts. The project will continue over a number years as the progress is evaluated. This project is a joint effort with other federal agencies and some of the effort is performed by academic researchers.

Turbulence. In addition to the work being performed by the JSAT under the Safer Skies Program, a PDT has a seven year plan to evaluate wind shear and turbulence around and on the approaches to Juneau, Alaska. Also, they are working with certain airlines to install instruments on aircraft with the capability to measure turbulence as sensed on the aircraft and report this information automatically. The data will be used to verify forecasts and to develop a standard index to report and warn for turbulence.

NEXRAD Enhancements. Work is continuing to develop improvements to the existing products and to develop some new graphics. Hardware and software pre-planned product improvements are are being pursued. These efforts are joint among DOT, DOD, and DOC.

Space Weather. Space Weather is of concern to the FAA in several areas of operations and regulations. Ionospheric scintillation creates certain errors in the Global Positioning System that affects navigation, especially for instrument approaches to airports. In programs for Wide Area and Local Area Augmentation Systems (WAAS and LAAS) corrections for these effects are being developed. This will be a very important advance to promote the Free Flight management of the National Airspace System. In addition, the effects on the ionosphere have grave impacts on the use of high frequency communications which are essential in air traffic control of flights across the oceans and over the poles of the Earth.

FAA is embarking in research at the Civil Aeromedical Institute in Oklahoma City on the radiation effects on fetuses of newly pregnant women when flying at high altitudes and at high latitudes where exposure is increased. The exposure of flight crews to this hazard will be measured to determine if repeated flights in this regime may accumulate deleterious results.

FAA planners for commercial space operations are working on the weather requirements to set criteria for space launch activities. The commercial launch sites in California, Florida and Virginia are co-located with government sites where the weather support is available. However, at the new commercial space launch site in Kodiak, Alaska new criteria must be developed and established for standard procedures.

FEDERAL PROGRAMS IN SUPPORT OF ROAD WEATHER

The Road Weather Management Program

The Federal Highway Administration (FHWA) coordinates a number of activities aimed at improving safety, mobility, productivity, environmental quality and national security on the nation's highways with respect to weather threats. These activities include identification of weather impacts to build the case for road weather programs, research to advance the state of the art concerning road weather practices, and promotion of the best available practices. The FHWA acts through federal aid and national coordination since it does not operate the highway system or Road Weather Information Systems (RWIS) that serve state and local highway operators and the public and private highway users. FHWA activities are conducted as partnerships with other public agencies, private sector vendors, road users, and universities.

Weather cuts across many FHWA and related surface transportation modal activities. Coordination is centered in the Road Weather Management Program within the FHWA Office of Transportation Operations. Road weather activities are closely associated with the Intelligent Transportation System (ITS) Program as the framework for advanced road weather information and decision support. Road weather activities are dependent on, but distinct from, general meteorological activities in two respects. In terms of the geophysical focus, weather must be related to what happens near, on, and under road surfaces as it affects pavements, structures, vehicles and ITS components. In terms of operations, the focus is on the decisions that use road weather information as one of many resources. This has led to a decision-centered approach for defining the program, with road weather information on one side and effective actions to deal with road weather on the other. Program activities are then organized primarily by the ITS subsystems and decisions served: maintenance management, traffic management, emergency management and traveler information. However, a common information infrastructure, or "infostructure", within the ITS includes road weather observation. This observational system is emerging as a contribution to the general environmental observation system that underlies all weather products. The FHWA expects that as weather products advance, there will be a need for greater integration of observation, prediction and science in the total land/air/sea/space environment.

FHWA road weather activities extend back to the 1970s, but the current coordinating program began in 1997. Over the entire period, the FHWA has achieved both practical successes and an expanded vision for the road weather agenda. There is no question that among modes, surface transportation has the most lives, the most time, and the most value in commerce at risk to weather threats. The problem has been to identify distinct and useful roles with respect to weather within FHWA jurisdiction. With the surface transportation reauthorization in 2004, funding programs for an integrated "infostructure" system and a dedicated road weather research program are anticipated. This will enable a more vigorous attack on the many issues associated with past and current activities whose descriptions follow.

The Strategic Highway Research Program (SHRP)

The Strategic Highway Research Program (SHRP) was established by the United States Congress through the 1987 Surface Transportation Act. This Act obligated $150 million over five years to improve the performance and durability of our nation's roads. The SHRP program examined a number of different subject areas, but the one most closely related to road weather was winter maintenance within the highway operations subject area. The research program was active until 1993, producing specifications, testing methods, equipment, and advanced technologies. Following the success of the five-year effort, the FHWA coordinated a national program to work with state and local highway agencies to implement and evaluate the products. This phase, entitled SHRP Implementation, was funded through the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA). This Act obligated $108 million over six years, and was administered jointly by the FHWA, the American Association of State Highway and Transportation Officials (AASHTO), and the Transportation Research Board (TRB).

The SHRP products encompassed various technology areas. Reports on Anti-Icing and Road Weather Information Systems, published by 1993, were instrumental in raising awareness of the state of the art among highway operating agencies. Anti-icing techniques, requiring chemical application before snow fall and ice formation , have had a vital synergy with predictive road weather information, and have in turn led to demand for improved observation and prediction through RWIS.

The SHRP Evaluation and Implementation Database (*www.wsdot.wa.gov/fossc/OTA/SHRP/*) contains information on the SHRP Lead States Program, SHRP products and vendors, SHRP and other publications, discussion groups, a personnel directory, and a calendar of SHRP-related events. An important adjunct to the SHRP anti-icing studies was a follow-up field evaluation of techniques, conducted under the FHWA Test and Evaluation

Maintenance Decision Support System (MDSS)--Update

The Federal Highway Administration (FHWA) recently unveiled a functional prototype of the Maintenance Decision Support System (MDSS). The MDSS is a tool made specifically to assist State Department of Transportation personnel with guidance and recommendations associated with winter road maintenance activities. The goal of the project is to integrate state of the art weather forecasting components with customized best maintenance practice logic to provide precise forecasts of road conditions and roadway treatment recommendations. It is envisioned that the output of the MDSS will provide savings to the state by reducing the amount of materials applied to the road, minimizing labor and equipment costs by matching plow runs with expected weather conditions, and promoting safety by providing detailed recommendations optimized to maintain the highest level of service on roads.

The FHWA assembled a stakeholder group of representatives from two-dozen states, numerous private transportation weather forecasting companies, and members of academia to solicit requirements for a next generation decision support system for winter maintenance. These inputs were provided to a consortium of national laboratories, which leveraged existing cutting edge technologies with new components to create the prototype. Participating labs included the National Center for Atmospheric Research, NOAA's Forecast Systems Laboratory, NOAA's National Severe Storms Laboratory, the United States Army Corps of Engineers Cold Regions Research and Experimental Laboratory and the Massachusetts Institute of Technology's Lincoln Laboratory.

The MDSS contains several sophisticated components. In addition to utilizing weather models from the National Weather Service's National Centers for Environmental Prediction, the MDSS ensemble module provides one of the first applications of high-resolution mesoscale ensemble forecasting. The Road Weather Forecast System is a mature data fusion engine that uses model input, mesonet/Road Weather Information Systems (RWIS) observations and dynamic Model Output Statistics (MOS) to provide accurate forecasts. The Road Condition and Treatment Module (RCTM) ingests all of the weather data, executes algorithms to determine roadway temperatures and surface chemical concentrations, and integrates customized, best management practice information to produce route-specific treatment recommendations. A java-based display application presents the results to the operators using combinations of colorful maps, animations, and time series graphics. One of the most powerful aspects of the MDSS is its ability to allow the user to modify treatment recommendations in any number of "what if" scenarios.

Most of the MDSS will be available in the public domain for download on September 20, 2002. Information about the MDSS project and links to the software and documentation can be found at *www.rap.ucar.edu/projects/rdwx_mdss/index.html*

FHWA and the lab consortium plan to demonstrate the MDSS in one state over the winter of 2002-2003 to solicit feedback from state maintenance managers and to validate and verify the accuracy of both the weather forecasts and the treatment recommendations. For more information on the MDSS and the Federal Highway Administration's Road Weather Management Program, contact Paul Pisano at Paul.Pisano@fhwa.dot.gov or visit *www.ops.fhwa.dot.gov/weather*.

Program. Results appeared in 1998 as Project No. 28: Anti-Icing Technology.

The ITS Research Program

The synergy of treatment technique and RWIS development now continues in the FHWA Road Weather Management Program and is strongly allied with the ITS Program. The ISTEA of 1991 also established the ITS Program, including its research program that now funds most of the FHWA road weather activities. The ITS program in the United States is overseen by the ITS Joint Program Office (ITS-JPO), which is a cross-modal program hosted in the FHWA Operations Core Business Unit, where the Road Weather Management Program also resides.

While the ITS initially focused on automated highways and metropolitan areas, a rural focus was initiated in 1996. The rural ITS Program identified maintenance and weather as additional ITS focus areas, and recognized the need for total integration of the maintenance, traffic and emergency management functions across wide areas and between states. Maintenance management continued the SHRP heritage as the main focus of road weather concerns when the Road Weather Management Program was formed, initially as the FHWA "Weather Team", in 1997. However, the long term agenda continues to integrate road weather across the management functions, across modes, and for traveler information. The research activities below are within this overall weather-across-ITS strategy. The ITS is also the logical informational interface with the national weather information system.

The ITS Architecture and Standards

The ITS uses open system principles: a uniformly defined modular structure of information processes with known protocols for passing information between modules. The information may be free or for a price, but all ITS applications should be able to get the information needed to support transportation decisions. The National ITS Architecture is the modular structure and was one of the earliest tasks of the ITS program. Several equipment interfaces are then standardized under the category of National Transportation Communications for ITS Protocol (NTCIP) standards, and there are associated data object and message set standards. The ITS program is promoting use of the National ITS Architecture and its standards as requirements for federal aid to ITS deployments by the operating agencies.

Weather information was not an original focus of the National ITS Architecture, and weather information was defined as flowing from external sources with their own architecture and standards. As weather gains significance in the ITS, and as the interfaces between road weather and atmospheric weather need to be coordinated, the National ITS Architecture is being adapted. The Environmental Sensor Station (ESS) standard was recently approved. This NTCIP standard specifies data objects and formats between the remote surface-weather and road-condition sensor sites, and the central processing units for the data (e.g., in maintenance management offices and traffic management centers). The ESS standard will be effective in the integration of different vendors' systems, and create a uniform format for ingest of road weather data into the general environmental observation system.

Following the rural ITS program definition of weather and maintenance as ITS application areas, the National ITS Architecture has, within the last two years, developed the Maintenance and Construction Operations (MCO) user service. User services are the application-oriented requirements clusters for the architecture. Detailing of the architecture with respect to road weather and its maintenance applications, through the MCO user service requirements, was completed in 2002. Among the changes is definition of a Road Weather Information Service terminator in addition to the existing Weather Service terminator. Together, these represent the division of responsibility for road weather, now provided largely by private vendors and based on the ESS observations, and weather generally. The interfaces between the two types of services is then defined as being outside of the ITS. However, the FHWA maintains an interest in specific improvement in weather information that will enhance road weather prediction, such as higher resolution numerical modeling and better characterization of precipitation at the road surface. The interface from the ESS, which is within the ITS, to both the road and general weather services, is also a FHWA interest.

It is hoped that further detailing of weather applications in traffic and emergency management will lead to further architecture detailing in the years ahead. As the interface between the ITS and the evolving national weather information system becomes closer, the National ITS Architecture and standards will provide a technical basis for integration and promotion of open system principles. The National ITS Architecture, in its latest update, can be found at *itsarch.iteris.com/itsarch/*.

The Observing "Infostructure"

Surveillance is fundamental to the ITS. The state of roadways and traffic is basic to almost all ITS applications. The capabilities to observe traffic, facilities, and the environment around the roadways are becoming a necessary part of roadway facilities themselves. The information-generating part of the road infrastructure is dubbed the "infostructure". In 2002, the FHWA is drafting requirements to support infostructure funding as part of the surface transportation-authorizing act that will be effective in 2004.

Road weather sensing, through the ESS, will be a part of the "infostructure". However, there are many

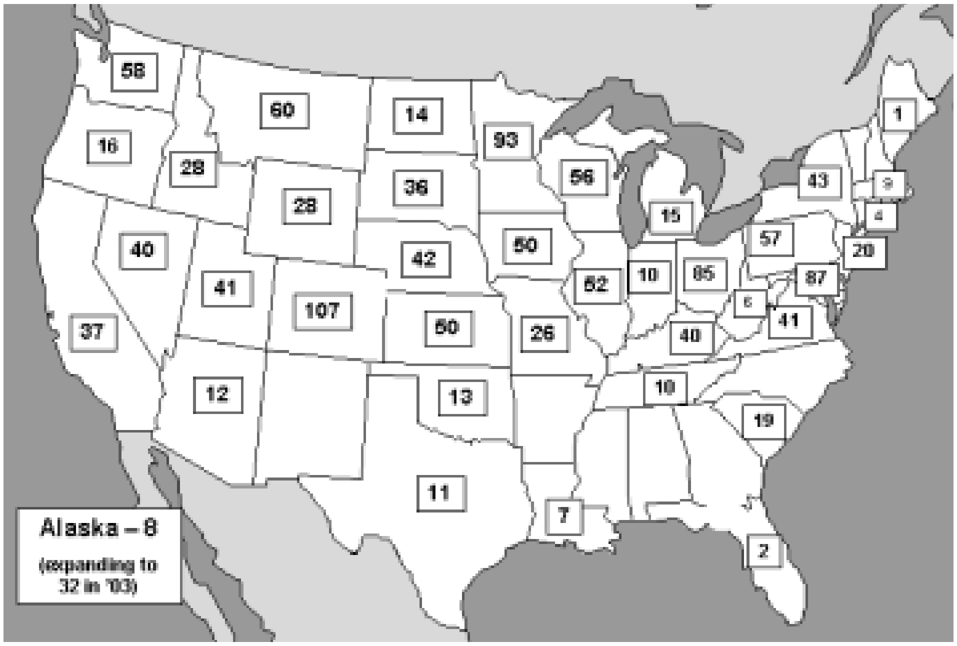

Figure 3-DOT-5. Census of Environment Sensor Station units deployed in each state.

aspects to road weather observation, and some substitutability between methods of observation. The authorizing legislation is focused on metropolitan ITS and concerned mainly with congestion management. Clearly, the need for ESS observations extends further. The ESS can be a vital part of homeland security, as well as more prosaic hazardous material (hazmat) spill and environmental management. Many types of fixed, mobile and remote platforms can observe relevant road conditions, especially road weather. But all observations ultimately support predictive information for decision support applications, even if the predictions just use persistence of what is observed. In the case of road temperature, the critical predictor for anti-icing at least, heat balance modeling relying on high-resolution numerical modeling of insolation and radiation can substitute for ESS observation. However, the use of ESS for spot hazard warning versus general area prediction, and the value of reinitializing heat balance models by ESS data require some level of deployment. The current census of ESS in the United States, by state, is shown in Figure 3-DOT-5.

Remote ESSs are generally fixed, with *in situ* sensors for the usual surface weather variables as well as road surface/subsurface temperature probes, covering water phase and depth, and chemical concentration/freezing point depression at the road surface. In some cases, and potentially over all road mileage, mobile sensors of the road condition are deployed. An important application of the mobile, and potentially remote, road temperature sensing is thermal mapping. This technique provides snapshots of complete road temperature profiles and is used both to select ESS fixed sites and to spatially predict temperatures based on time series predictors at the fixed stations. There are future possibilities for remote sensing of "skin temperature" on roads and adjacent surfaces, by Unmanned Aerial Vehicles (UAVs) and satellites (especially the next generation polar orbiters). This could make a limited deployment of fixed sensors more effective and improve the initialization of heat balance models.

At present, ESS data across the United States are neither integrated nor open. The data are not centrally collected, in standard format, available to all users, nor uniformly used. However, regional efforts are paving the way for both openness and integration. So-called mesonets (mesoscale meteorological networks) within states and across states, usually under university auspices, are integrating the data across many observational systems. The data are used in some cases to validate weather forecasts and analyses, and in the rare case, but nowhere are they used, like other surface observations, for ingest into numerical weather prediction models. In order to address these issues, the FHWA is participating in the Committee on Integrated Observing Systems (CIOS) of the OFCM. From the FHWA perspective, the purpose of CIOS involvement is to: (1) arrive at an efficient allocation of observations to platforms, including the ESS; (2) establish further open-system interfaces for environmental observations with the ITS; and (3) improve the incorporation of ESS into the general environmental prediction process. The motivation is that better environmental prediction, including the dispersion of toxic substances in homeland defense or environmental management, must consider all interactions between the land, air and sea domains. It is expected that roadway observing platforms will become more important over time and serve both specific road-management and general environmental-management purposes.

The focus of the FHWA remains on the application of ESS observations to highway-related decision-making. In 2001, the FHWA sponsored a set of five Cooperative Program for Meteorological Education and Training (COMET) projects that became the first to add state DOTs to the traditional university and NWS partners. These projects are ongoing in 2002 and should be completed in 2003. In five states (Iowa, Nevada, New York, Pennsylvania, and Utah), the projects are improving the use of the ESS data, through various predictive techniques and decision support applications.

Decision Support

Under previous efforts within the program, Rroad weather users early identified requirements as the trinity of "relevance, accuracy and timeliness". Those criteria were selected primarily in reaction to synoptic scale forecasts that were: (1) not relevant to climatically localized road hazards; (2) not accurate at such points or at the long time horizons predicted for; and (3) not delivered at better than the twice-daily updates nor at frequent prediction times in between. Improvements in that situation, including National Centers for Environmental Prediction (NCEP) models at mesoscale resolution and as frequent as hourly updates, are significant, and largely not in response to specific road-weather requirements. The related improvements in regional and private numerical prediction are also helpful, but only partially driven by road weather requirements. This is what motivated the attention away from environmental prediction to the fusion and presentation of existing information, whatever it's quality. This was in response to the evident problem that almost all weather-related transportation decisions do not rely on one weather information source, nor on weather information alone. The gap most in need of attention was between increasingly good and plentiful information, and the specific decision at hand. This is the area of FHWA decision support research and development.

Decision support is where tailoring occurs. Each decision is specific to a kind of intervention (traveler information, snow and ice treatment, road closure, modified signal timing, etc.), a particular place and time, and the characteristics of the decision maker (their expertise, their location, their information processing equipment). In most cases, projects to support decisions about weather threats have also made some contribution to the environmental prediction inputs. The following are several important projects undertaken with FHWA support.

The Surface Transportation Weather Decision Support Requirements (STWDSR) Project

In 1999 and 2000, decision support requirements, first generally and then specifically for winter road maintenance, were studied in the Surface Transportation Weather Decision Support Requirements (STWDSR) project. This project used weather threat scenarios to identify specific decisions made in winter road maintenance, their timing, and the expected confidence of the decisions at various time horizons. The STWDSR project became an important contributor to the OFCM's Weather Information for Surface Transportation (WIST) needs analysis, the National ITS Architecture modifications, and to the Maintenance Decision Support System (MDSS) prototype project.

The MDSS Project

The Maintenance Decision Support System (MDSS) project is a multi-year effort to prototype and field test advanced decision support components for winter road maintenance managers. The development of a prototype MDSS is part of the Surface Transportation Weather Decision Support Requirements (STWDSR) initiative conducted by Mitretek Systems, Inc. The documents STWDSR V2.0[1] and the MDSS Project Plan[2] give background information on the project and operational concept for decision support associated with winter road maintenance. These documents explain the process used by the FHWA and stakeholder groups (users, vendors, and researchers) to produce the MDSS prototype.

The MDSS is based on leading diagnostic and prognostic weather research capabilities (high resolution numerical forecast models and experimental algorithms) and road behavior (surface and subsurface), which are being developed at six national research centers. It is anticipated that components of the prototype MDSS system developed by this project will ultimately be deployed by road operating agencies, including state departments of transportation (DOTs), and generally supplied by private vendors.

The MDSS project goal is to develop a prototype capability that: (1) capitalizes on existing road and weather data sources, (2) augments data sources where they are weak or where improved accuracy could significantly improve decision-making tasks, (3) fuses data to create an open, integrated and understandable presentation of current environmental and road conditions, (4) processes data to generate diagnostic and prognostic maps of road conditions along road corridors, with emphasis on the one- to 48-hour horizon (historical information from the previous 48 hours will also be available), (5) provides a display capability on the state of the roadway, and (6) provides a decision support tool that includes recommendations on road maintenance courses of action. All of the above will be provided on a single platform, with simple and intuitive operating requirements in a readily comprehensible display of results and recommended courses of action, together with anticipated consequences of action or inaction.

With user needs in mind, a conceptual structure of the prototype MDSS has been developed. The prototype MDSS is divided into five primary elements as shown in Figure 3-DOT-6.

Advanced Transportation Weather Information System (ATWIS)

The Advanced Transportation Weather Information System (ATWIS) project was started in 1995 at the University of North Dakota and has become operational under a private entity (Figure 3-DOT-7). The original system provided route-specific road weather information for travelers on the main routes in North and South Dakota. Service has since been

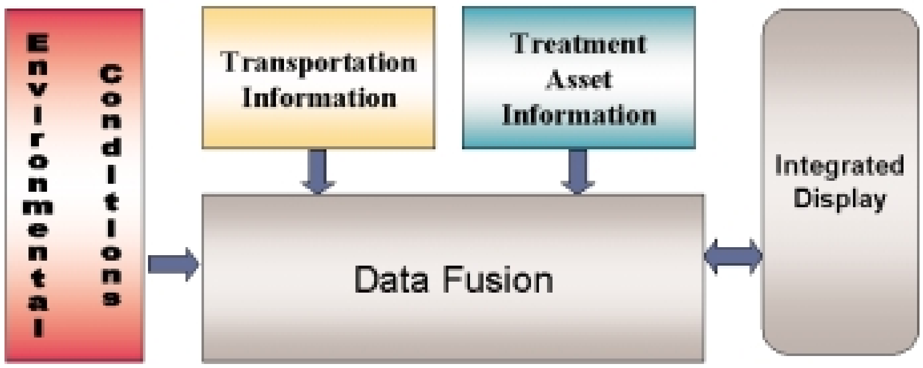

Figure 3-DOT-6 . Schematic of FHWA's Maintenance Decision Support System.

expanded into Minnesota and Montana. For travelers, the primary decision support is on the routing and timing of trips and layovers. The primary purpose of the ATWIS research program is to demonstrate how current technologies in weather forecasting, weather analysis, telecommunications, and road condition monitoring can be merged effectively to produce a safer and more efficient transportation system for both commercial and general travel. ATWIS operates its own mesoscale numerical model, analyzed to road conditions on segments of the Interstate freeway and arterial system in its states. Information is conveyed interactively to travelers, primarily via cellular telephone.

Key areas of interest of this project include:

- public use and acceptance of road weather information,
- the added value of highly accurate weather forecasts,
- information dissemination methods and the role of telecommunications,
- the need for 24-hour operations,
- the role of road condition monitoring,
- how to generate efficient forecasts, and
- commercial viability of the system.

ATWIS is currently looking at deployment of the MDSS for maintenance management decision support as part of a multi-state pooled fund project. ATWIS is also the basis for road weather information in regional 511 traveler information services described below.

FORETELL

With the intent of integrating RWIS with other ITS services, the FORETELL project was initiated in 1997 with federal, state and private funds in Iowa, Missouri, and Wisconsin. FORETELL became operational through its private operator in 2000. FORETELL was an MDSS precursor and focuses on detailed decision support for road maintenance with the development of heat balance models in combination with mesoscale numerical modeling. Internet, telephone and fax dissemination media also make FORETELL products available to the general public as traveler information. An important outgrowth of the FORETELL project has been the inter-state exchange of weather and other road condition information in a Condition Acquisition and Reporting System (CARS). The CARS has been a vehicle for promoting more complete weather information in the ITS center-to-center data dictionaries and message set standards. CARS is being deployed in several states beside the core FORETELL states. FORETELL's objectives include:

- integrating RWIS across state borders,
- assimilating all of the existing weather and road condition data sources,
- cutting costs and substantially benefiting the environment by increasing the levels of forecasting detail,
- improving timeliness and accuracy of road weather information, and
- using multiple media for information dissemination.

In order to evaluate these objectives, the FHWA also sponsored the first three-year evaluation of an ITS project, in an attempt to detect effects despite annual weather variations. The results of this analysis are due late in 2003.

Emergency Management

Emergency management, focusing on hurricane evacuation operations, has become the second major focus of the Road Weather Management Program after winter road maintenance. This activity has been motivated primarily by the traffic implications of evacuation for Hurricane Floyd, and the need for some federal role in coordinating state evacuation plans. Activities are focusing on the ring of states from Texas to Virginia, most liable to the hurricane threat and in need of evacuation from landfall areas.

The hurricane evacuation activity is motivated by a weather threat, but then is devoted to transportation activities prior to any threat occurring. The object is to get people away from the threats of storm surge and coastal winds before they hit. Inland flooding; usually following the evolution of the tropical storm itself, has typically been the biggest source of fatalities, and can do the most damage to structures; is practically a separate problem. The approach to the hurricane issue has had to be much different from that of winter maintenance where the inland weather threat is immediate and primary.

Hurricane landfall is a major operational and research focus of the National Weather Service (NWS). The ability to localize landfall in time and space, but at long prediction horizons, is the major factor in all emergency and transportation management decision making. One problem has been the tradeoff of resolution for longer time leads. This has been driven by the time needed to evacuate growing coastal populations, but in turn results in more people evacuated over larger

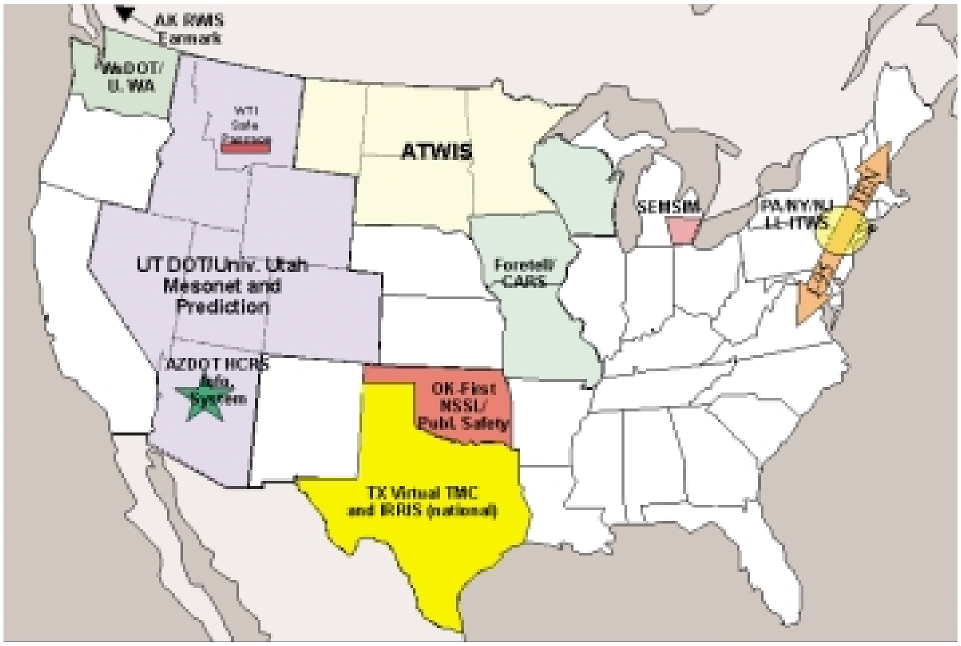

Figure 3-DOT-7 . Regional Weather Information systems.

areas with more traffic congestion as a result. Hurricane Floyd was a prime example of this problem.

The hurricane evacuation component of the FHWA program has focused on: (1) deployment of a transportation/ evacuation planning tool called the Evacuation Traffic Information System (ETIS); (2) promoting intra- and interstate evacuation planning and transportation-operations; (3) documenting the state of the art and the state of the practice in evacuation traffic management; (4) initiating planning for demonstration of improved practices; and (5) enhancing the traffic management role to complement the evacuation and recovery role of the emergency management agencies. The ETIS was developed originally under Corps of Engineers auspices but is now under FHWA sponsorship, and operation by its private developers. Exercises involving the tool are providing information that can lead to improved tools and practices. A series of multi-state workshops were conducted in 2002, leading to further grants for planning of improved practices and inter-state, multi-agency coordination. Improved weather information is not a FHWA focus in this case. However, in 2002 the FHWA also began participating in sponsorship of the United States Weather Research Program (USWRP), which has been a center of hurricane landfall and intensity prediction research. More attention to the inland consequences of hurricanes may eventually link the emergency, traffic, and maintenance management components of the FHWA program into a truly integrated approach to weather threats.

N511 National Traveler Information Service

Just as dialing 911 is the standard way to access emergency aid over the telephone, it was thought that a standardized number for travel information would be beneficial. Accordingly, a broad coalition of ITS interests, with technical support to the FCC docket submission by the FHWA, achieved in 2001 the allocation of a national 511 (N511) traveler information number. In 2002, the FHWA sponsored a number of grants to plan for state deployment of the N511 service, and guidelines were issued on service content. A survey on traveler information conducted by ITS America indicated that weather and road condition information was highest in demand by travelers. Therefore, road weather information should be a key component of N511 services. The means of delivering information through N511 is still being developed, including ways to serve peak demands for emergency evacuation information, as part of the homeland defense or other threat capability. However, components previously developed components for road weather information previously are bound to be important. That includes the route and road-specific information developed through the ATWIS, FORETELL, MDSS and other projects, and the capability for open-system information sharing of the National ITS Architecture. The N511 program also must find ways to complement NOAA Weather Radio broadcasts (and eventually an all-hazards warning system), and use the NWS official watches and warning information. The N511 capability is just one more way in which ITS is becoming a significant dissemination means for weather information.

Impacts on Mobility

While the costs of weather to surface transportation must be are immense, it has been difficult to quantify specific costs or the benefits (as avoidable costs) through better information to support better treatment and response. It is likely that the costs to mobility, in terms of delay due to weather, are the largest component. Initial estimates of the economic impact of weather-related delay on trucks in the 20 major metropolitan areas most affected by adverse weather is on the order of $2 billion per year. Some delays are due to well-defined closure events. These are due to storms that swamp reasonable treatment activities, but could benefit from more authoritative travel-demand management techniques. This leaves the much more prevalent, and subtle, delays due to more minor threats, like rain, residual snow, or visibility impairments that are difficult to treat in any way. If there are traffic management strategies to address them, they probably have to be based on very good, dynamical, predictions of both weather and traffic. However, it is clear from traffic flow theory that with heavy volumes, as in metropolitan areas at peak times, very small changes in effective capacity (as due to a change in road friction) or very small changes in traffic volume can have large delay effects.

The FHWA is sponsoring closer analysis of delay effects due to weather, work zones and incidents. Paucity of good traffic and road weather data sets has hindered the analysis, but in 2001 and 2002, analyses were conducted for Seattle and Washington, DC metropolitan areas. These combined surface weather observations with traffic speed data, both empirical and modeled. The results have been consistent in showing about a 12 percent increase in travel time averaged over a wide range of weather events. This research will continue, with more metropolitan areas to be analyzed, extension to non-metropolitan areas, and use of Doppler radar data for more precise and more dynamic inference of road-weather conditions. This in turn can lead to a stronger attack on delays through traffic management practices, including demand management, possible routing advisories, and weather-adaptive signal timing. A separate study performed by the Oak Ridge National Laboratory estimates 23 percent of the non-recurrent delay on highways is due to snow, ice and fog. This amounts to an estimate of 544 million vehicle-hours of delay per year.

Best Practices

The Road Weather Management Program is documenting best practices of maintenance managers, traffic managers and emergency managers in response to various weather threats. Best practice case studies demonstrate the entire information thread, from threat information to performance information. This thread begins with observation of weather, road surface, traffic and other conditions to identify threats to transportation system performance. Based upon credible threat information, managers execute operational techniques that improve transportation outcomes-safety, mobility and productivity. Examples of successful operational techniques follow.

A maintenance division of the Montana DOT employed mobile anti-icing and de-icing strategies to proactively respond to winter storms. When performance was compared to a maintenance division that used reactive treatment after storms, it was found that labor, material, and equipment costs for the proactive division were 37 percent lower the reactive division. Additionally, a higher level of service was achieved on road sections treated by the proactive division resulting in safety and mobility improvements.

On a 19-mile section of Interstate 75 in Tennessee, a Fog Detection and Warning System collects data from two ESS, eight fog detectors, and 44 vehicle speed detectors to predict and detect conditions conducive to fog formation, and alert managers when established threshold criteria are met. Traffic managers may select pre-programmed dynamic message sign (DMS) messages, pre-recorded highway advisory radio (HAR) broadcasts, and/or alter speed limits via variable speed limit (VSL) signs based upon response scenarios proposed by the system. When visibility is less than 240 feet, the worst-case scenario, the Highway Patrol activates eight automatic ramp gates to close the affected interstate section and detour traffic to US Route 11. Between 1973, when the interstate opened, and 1994; there were over 200 crashes, 130 injuries and 18 fatalities on this highway section. Since the fog detection and warning system began operating in 1994, safety has been significantly improved and no fog-related accidents have occurred.

During the Hurricane Floyd evacuation in 1999, traffic and emergency managers with South Carolina DOT and the State Highway Emergency Patrol (SHEP) had not agreed on a lane reversal plan for Interstate 26 prior to hurricane landfall. As a result, there was severe congestion on this route with a maximum per lane volume of roughly 1,400 vehicles per hour. Managers quickly developed a lane reversal plan for reentry operations. DMS and HAR were deployed to alert travelers of closures and alternate routes, and westbound lanes were reversed. Maximum volumes during reentry exceeded 2,000 vehicles per hour per lane-a 43 percent increase over evacuation volumes. The use of lane reversal and traveler information techniques improved mobility by significantly increasing roadway capacity.

The Federal Railroad Administration (FRA) supports improving the collection, dissemination, and application of weather data to enhance railroad safety through the Intelligent Weather Systems project, as part of the Intelligent Railroad Systems and Railroad System Safety research programs. These programs address safety issues for freight, commuter, intercity passenger, and high-speed passenger railroads.

Intelligent Weather Systems for railroad operations consist of networks of local weather sensors and instrumentation - both wayside and on-board locomotives - combined with national, regional, and local forecast data to alert train control centers, train crews, and maintenance crews of actual or potential hazardous weather conditions. Intelligent weather systems will provide advance warning of weather-caused hazards such as flooding; track washouts; snow, mud, or rock slides; high winds; fog; high track-buckling risk; or other conditions which require adjustment to train operations or action by maintenance personnel (Figure 3-DOT-8). Weather data collected on the railroad could also be forwarded to weather forecasting centers to augment their other data sources. The installation of the digital data link communications network is a prerequisite for this activity.

Figure 3-DOT-8. Track washed out by flood waters from Hurricane Alberto.

FRA intends to examine ways that weather data can be collected on railroads and moved to forecasters, and ways that forecasts and current weather information can be moved to railroad control centers and train and maintenance crews to avoid potential accident situations. This research is estimated to continue for 5-6 years after it begins. This is one of the partnership initiatives identified in the NSTC's *National Transportation Technology Plan*.

The Federal Transit Administration's (FTA) mission is to "*provide leadership, technical assistance and financial resources for safe, technologically advanced public transportation which enhances all citizens' mobility and accessibility, improves America's communities and natural environment, and strengthens the national economy*." In this context, FTA provides an energy efficient means of transporting people, thereby, reducing emissions caused by transportation and lessening the Nation's dependence on fossil fuels, including foreign oil. One-hundred gallons of fuel can be saved each year for every person riding the bus instead of driving. The savings by train and trolley riders are even greater (Figure 3-DOT-9).

Figure 3-DOT-9. Rail Transit in Southern California.

The United States Department of Transportation (DOT) has a variety of research development and demonstration programs and initiatives that are targeted at reducing the emissions and improving the efficiency of vehicles including trucks, buses, marine vessels, airport support equipment, and other specialty vehicles. The underlying assumption of many of these public-private partnership efforts is to improve current vehicles without sacrificing vehicle performance or limiting consumer choices in the marketplace.

In particular, the FTA Fuel Cell Transit Bus Program and the Hybrid Electric and Electric Bus Program focus on developing and demonstrating innovative transit bus technologies that can improve the energy efficiency and reduce harmful emissions from transit buses, including greenhouse gas emissions. Through these efforts, the benefits and viability of both fuel cells and hybrid electric drive technology for transit bus applications are being demonstrated.

Similarly, the Advanced Vehicle Technologies Program (AVP) managed by DOT, is a collaborative program between the Federal government and over 500 companies, universities, national laboratories, state, regional, and local governments focused on innovative technologies for medium and heavy-duty vehicles that can lessen the transportation sector's dependence on foreign oil, reduce emissions from transportation vehicles, and enhance the development of a domestic advanced transportation industry. The technologies developed and demonstrated under the program are closely related to transit research needs, or directly develop and demon strate advanced technologies for transit.

The Transit Cooperative Research Program is currently researching FTA's role in avoiding greenhouse gas emissions. Project H-21 is examining how transit service can contribute to community sustainability and provide enhanced mobility while addressing climate change at the community and regional level.

One example of research for vehicle emissions is with the Desert Research Institute (DRI) to develop and test a new remote sensing device that accurately estimates particulate emissions from motor vehicles and will quantify the contributions of ozone precursor and small particular emissions from sources outside the Las Vegas metropolitan area. The meteorological and air quality modeling will attempt to quantify the level of emissions transported into the area from the Los Angeles South Coast Air Basin.

In FTA's national rural and parks programs coordinated with the research efforts currently underway with the Weather Information for Surface Transportation (WIST) initiative. This research will take advantage of other related rural ITS weather resources to integrate transit and emergency services through the "Common Communication Backbone Concept." Many rural areas can greatly benefit from a Joint Operational center that consolidates transit management, emergency management, and emergency medical service operations utilizing light rail, ferry, van, and bus transit services. This integrated management and transit emergency service will enable rural transit operators to manage weather-related incidents more efficiently, while improving the coordination with travelers and emergency management staffs (Figure 3-DOT-10).

Figure 3-DOT-10. Weather poses a significant impact on transit operations in the Washington metropolitan area. (WMATA Photograph)

Although no United States Coast Guard (USCG) cutters or shore units are solely dedicated to meteorology, they collectively perform a variety of functions in support of the national meteorology program. USCG ocean-going cutters and coastal stations provide weather observations to the National Weather Service (NWS). Coast Guard communications stations broadcast NWS marine forecasts, weather warnings, and weather facsimile charts and, also, collect weather observations from commercial shipping for the NWS. The Coast Guard also operates the LORAN C radionavigation system and the Maritime Differential GPS (DGPS) Service. The LORAN C system provides Position, Navigation, and Timing (PNT) information to a variety of navigation and non-navigation users throughout the continental United States and Alaska (e.g. radiosondes). The Maritime DGPS Service is an augmentation to the GPS that improves GPS-only accuracy to better than ten meters and provides DGPS coverage to coastal areas of the continental United States, the Great Lakes, Puerto Rico, portions of Alaska and Hawaii, and portions of the Mississippi River Basin.

Coast Guard operates three polar icebreakers - USCGC POLAR STAR, USCGC POLAR SEA, and USCGC HEALY - to serve our Nation's security, economic, environmental, and scientific interests. These vessels make important marine environmental measurements during dedicated science deployments or in conjunction with other missions.

USCGC HEALY, a new icebreaking research vessel, was delivered to the Coast Guard in November 1999 and conducted successful shakedown tests of the hull, machinery, and scientific equipment during January-August 2000 (Figure 3-DOT-11). The first unrestricted science cruise was conducted in the Eastern Arctic in the summer of 2001. HEALY, has a length of 420 feet, beam of 82 feet, and displaces over 16,000 tons. Scientific systems

Figure 3-DOT-11. USCGC HEALEY, the Coast Guard's new icebreaking research vessel, conducting ice trials.

and gear include a bottom mapping multi-beam sonar system; a sub-bottom profiling system; a conductivity-depth-temperature data system; an expendable oceanographic probe system; an Acoustic Doppler Current Profiler; a jumbo coring system; a continuous flow, seawater sampling system; a meteorological measurement system; and a bow tower for clean air experiments. To schedule time on HEALY, see the UNOLS web site, *www.unols.org*. For more information, see the Coast Guard web page for HEALY, *www.uscg.mil/pacarea/healy/*.

USCG maintains the International Ice Patrol (IIP) which uses sensor-equipped aircraft to patrol the Grand Banks of Newfoundland to locate and track icebergs which pose a hazard to North Atlantic shipping. Direct observations are supplemented and extrapolated using a numerical iceberg drift and deterioration model. IIP determines the geographic limits of the iceberg hazard and, twice daily, broadcasts iceberg warning bulletins and ice facsimile charts which define the limits of the iceberg threat during the iceberg season (spring and summer). IIP annually archives data on all confirmed and suspected targets, and forward these data to the National Snow and Ice Data Center. These data can be accessed via the IIP web page *www.uscg.mil/lantarea/iip/home.html*. Archived data contains all iceberg sighting data along with the last model-predicted position of each berg.

The Coast Guard participates with the Navy and NOAA in conducting the National Ice Center, a multi-agency operational center that produces analyses and forecasts of Arctic, Antarctic, Great Lakes, and coastal ice conditions.

The Coast Guard also collaborates with NOAA in operating the National Data Buoy Center (NDBC) which deploys and maintains NOAA's automated network of environmental monitoring platforms in the deep ocean and coastal regions. Five Coast Guard personnel fill key technical and logistics support positions within NDBC. Coast Guard cutters support the deployment and retrieval of data buoys, and provide periodic maintenance visits to both buoys and coastal stations, expending approximately 180 cutter days annually. Coast Guard aircraft, small boats, and shore facilities also provide NDBC support.

Meteorological activities are coordinated by the Icebreaking Division of the Office of Aids to Navigation at Coast Guard Headquarters. Field management of Coast Guard meteorological support services is accomplished as the Coast Guard Area and District levels.